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DISTRIBUTION OF TURBULENT FLOW ON FLAT PERPENDICULAR OBSTRUCTION

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ABSTRACT. Experimental investigations are described which show that during the spreading of subsonic and supersonic turbulent air flows, there is similarity in the distribution of the velocity thrust, excess stagnation temperature and excess static pressure on the surface of the obstacle. The distribution of these values with respect to the dimensionless coordinate ϕ at various distances from the section of the jet obeys empirical laws that are common to the various flows.

Investigations of the basic part of turbulent flows of compressed gas have demonstrated the similarity of profiles of dynamic pressure ρU^2 [1]. In the case of the spreading of a flow on a flat unbounded obstacle located in the basic section of the flow, it is natural to assume that the distribution of dynamic pressure on the surface of the obstacle will also be similar. In order to check this assumption we made an experimental investigation of the parameters of supersonic turbulent air flows spreading over a flat unbounded obstacle. The parameters of the gas through the section of the jets of the three investigated flows and the dimensions of the jets are given in the table. /115*

We investigated the spreading of flow on an obstacle with a diameter of 600 mm (Figure 1), upon which were placed, at various distances from the center, paired manifolds with Pitot tubes and manifolds with thermocouples for stagnation temperature. A series of drainage apertures was made on the surface of the obstacle for the purpose of measuring the statistical pressure. The investigation was carried out for obstacle-jet section distances s of 15 and /116
20 d_a in the design mode, 30 d_a in the underexpansion mode and 15 d_a in the overexpansion mode.

For the purpose of processing the experimental data of the present work and of [2-4], in which the experimental data are given for the spreading of

*Numbers in the margin indicate pagination in the foreign text.

subsonic air flows, we used a coordinate borrowed from the Tolmin solution for an axisymmetric turbulent source [5] as the dimensionless coordinate:

$$\varphi = \frac{r}{ax},$$

where r is the distance from the center of the obstacle; x = s + h is the distance between the pole of the flow to the obstacle; a is the turbulence constant; h is the distance between the flow pole and the section of the jet in the free incident flow.

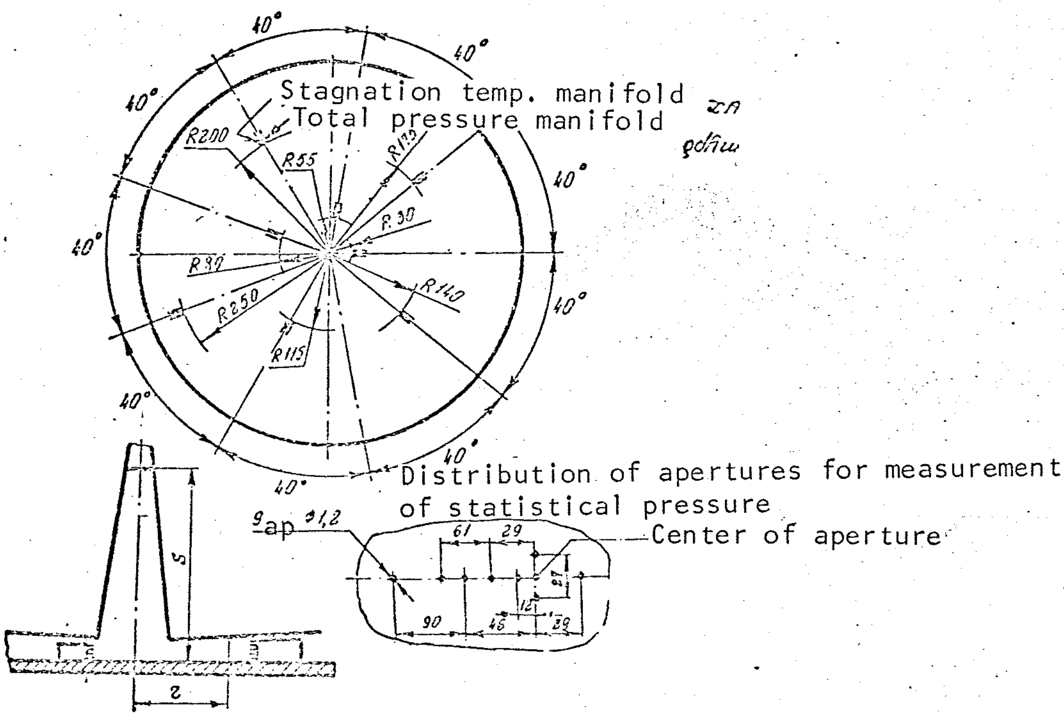

Figure 1

Thus, for representing the distribution of the parameters of the flow during its spreading through dimensionless radius ϕ, it is necessary to know the values of a and h in the free incident flow, which were determined on the basis of the dynamic pressure drop along the free flow axis.

For the investigated flows the following data were obtained:

$$M_a = 2{,}43, \quad a = 0{,}0555, \quad h = -3{,}8d_a,$$
$$M_a = 2{,}7, \quad a = 0{,}0556, \quad h = -3{,}2d_a,$$
$$M_a = 1{,}64, \quad a = 0{,}058, \quad h = 0.$$

For the flow investigated in [2], a = 0.068 and h = $3d_a$. In [3] h = $1.7d_a$ hence a = 0.066. In [4] the free flow was not investigated, and therefore the following values were used in accordance with [5]: a = 0.07, h = $2.5d_a$.

These values made it possible to construct the distribution of dynamic pressure and stagnation temperature on the surface of the obstacle with respect to dimensionless radius ϕ. Figures 2 and 3 show the results of processing of the experimental data of the present work and of [2-4]. The figures show that the distribution of dynamic pressure and stagnation temperature through dimensionless radius ϕ during spreading on the obstacle at various distances from the section of the jet actually obeys laws that are common to all investigated flows, which can be approximated by the expressions:

$$\frac{\rho U^2}{\rho U_{\max}^2} = 32\varphi^2 e^{-3{,}5\sqrt{\varphi}}. \tag{1}$$

Here $\rho U_{\max}^2$ is the maximum velocity head on the obstacle surface and /117

$$\frac{\Delta\theta}{\Delta\theta_m} = e^{-1{,}1\varphi^{0{,}1}}, \tag{2}$$

where $\Delta\theta_m$ is the stagnation temperature on the axis of the flow.

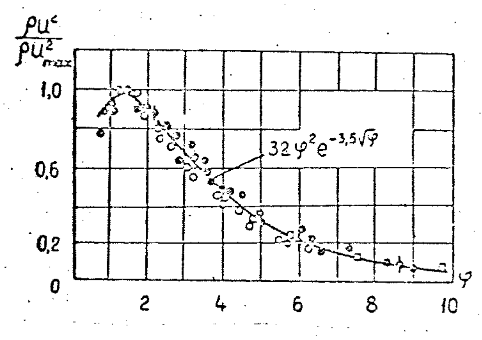

Figure 2

• -- According to data of the present work; o -- according to [2]; ф -- according to [3]; □-- according to [4].

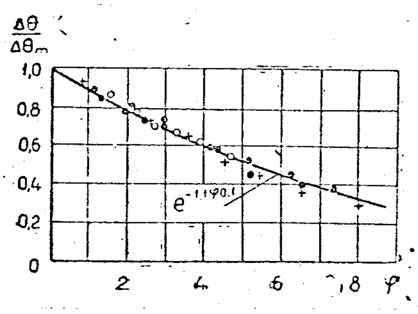

Figure 3

○ — M_a = 1,64; • — M_a = 2,43; + — M_a = 2,7.

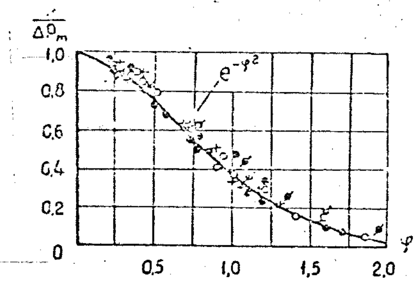

Figure 4

○ — $M_a = 1{,}64$; ○ — $M_a = 2{,}43$; + — $M_a = 2{,}7$; ○ — according to [3].

From the similarity of ρU^2 in the free flow for large Mach numbers M_m along the flow axis, according to Newton's hypothesis, there should be similarity also in the distribution of the excess static pressure ΔP on the obstacle. However, as borne out by the experiment, it also occurs for small Mach numbers M_m (Figure 4). According to experimental data the distribution of static pressure with respect to coordinate ϕ on the surface of the obstacle, represented in Figure 4, can be approximated by the following relation:

$$\frac{\Delta P}{\Delta P_m} = e^{-\varphi^2}, \tag{3}$$

where ΔP_m is the excess pressure at the center of the obstacle, determined by the number M_m. The value ρU^2_{max} can be represented in the form

$$\rho U^2_{max} = k_j \cdot k_f \cdot \rho U^2_m,$$

where ρU^2_m is the velocity thrust on the flow axis prior to the compression jump;

k_j are velocity thrust losses on the jump;

k_f are the velocity thrust losses to friction.

For k_j we write

$$k_j = \frac{\rho U^2_{0\,max}}{\rho U^2_m},$$

where $\rho U^2_{0\,max}$ is the maximum velocity thrust on the surface of the obstacle in the absence of friction.

Taking the distribution of static pressure on the obstacle in accordance with expression (3), we can write the velocity thrust distribution on the obstacle surface in the absence of friction

$$\rho U_0^2 = \frac{2k}{k-1} P\left[\left(\frac{P_m}{P}\right)^{\frac{k}{k-1}} - 1\right]. \tag{4}$$

From equation (4) we know that the maximum ρU_0^2 will be obtained when the pressure ratio is

$$\frac{P_m}{P} = k^{\frac{k}{k-1}},$$

hence the static pressure corresponding to maximum ρU_0^2 is

$$P = P_m \cdot k^{-\frac{k}{k-1}}.$$

By substituting the pressure ratio into expression (4) we obtain /118

$$\rho U_{0\,\max}^2 = 2P_m \cdot k^{-\frac{1}{k-1}}.$$

We will express P_m and ρU_m^2 through the Mach number on the flow axis, then for k_j we obtain, when $M_m > 1$

$$K_j = \frac{2\sigma_j\left(1 + \frac{k-1}{2} M_m^2\right)^{\frac{k}{k-1}}}{k^{\frac{k}{k-1}} \cdot M_m^2},$$

where σ_j is the coefficient of pressure recovery on the forward jump.

The coefficient of losses to friction during the spreading of subsonic air flows, investigated in [6], is $k_f = 0.9$-0.92.

During the spreading of supersonic flows investigated in the present work, it was found that when $M_m = 1.2$-2.4, the coefficient of losses to friction $k_f = 0.84$-0.9.

Thus, the experimental investigations described herein have shown that during the spreading of subsonic and supersonic turbulent air flows, there is similarity in the distribution of the velocity thrust, excess stagnation temperature, and excess static pressure on the surface of the obstacle. The distribution of these values with respect to the dimensionless coordinate ϕ at various distances from the section of jet obeys empirical laws, defined in this work, that are common to the various flows.

	Symbols	Design spreading mode	Spreading with under-expansion	Spreading with over-expansion
Mach number in cross section of jet	M_a	2.43	1.64	2.7
Static pressure in cross section of jet, n/m^2	P_a	$9.8 \cdot 10^4$	$34.3 \cdot 10^4$	$6.86 \cdot 10^4$
Stagnation pressure, n/m^2	P_{0n}	$1.57 \cdot 10^4$	$1.57 \cdot 10^4$	$1.57 \cdot 10^4$
Excess stagnation temperature, °C	$\Delta\theta_{0n}$	330	330	330
Diameter of critical cross section of jet, m	d_{cr}	$28 \cdot 10^{-3}$	$28 \cdot 10^{-3}$	$28 \cdot 10^{-3}$
Diameter of outlet cross section, m	d_a	$44 \cdot 10^{-3}$	$31.8 \cdot 10^{-3}$	$50 \cdot 10^{-3}$

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